Paper Number 2004-01-016

WEB-BASED SURVEILLANCE AND AUDITING TOOL (WEBSAT): A PROACTIVE SYSTEM TO CAPTURE MAINTENANCE ERRORS

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Surveillance and auditing of maintenance activities is an important function to improve aviation safety. Significant efforts have been invested to investigate and track inspection and maintenance errors. Although valuable in terms of their insights into identifying the performance-shaping factors leading to maintenance errors, these efforts tend to be reactive in nature. They are not preventive measures, but rather investigations of maintenance accidents and errors subsequent to their occurrence. A system that documents the processes and outcomes of maintenance activities and makes this documentation more accessible offers the promise of reduction of future maintenance error rates. Such a system would then support more robust and safer aircraft maintenance operations. This paper addresses the development of a web-based surveillance and auditing tool (WebSAT) which promotes a standardized format for data collection, data reduction and data analysis across airlines to proactively identify the factors contributing to improper maintenance.

Introduction

The mission of the Federal Aviation Administration (FAA) is to provide the public with continuing safe and reliable air transportation and to ensure airworthiness of aircraft. This mission can be fulfilled by minimizing aircraft accidents. Maintenance error has been found to be a crucial factor in aircraft accidents (Boeing and US ATA, 1995). The increasing number of maintenance and inspection errors in the aviation industry motivated the need for human factors research in this area (FAA 1991, 1993). Human factors research in maintenance deemed the human as the central part of the aviation system (Gramopadhye and Drury, 2000). This human factors research considers the psychophysiological aspects of the human and explains the need for developing different human factors interventions which ensure that task, job and environment are defined judiciously to match human capabilities and limitations. This enduring emphasis on humans and their role in aviation system results in the development of error-tolerant systems.

Federal agencies and other regulatory bodies ensure that safety and regulatory compliance procedures are met by the airline industries. In order to minimize maintenance errors, the aviation maintenance industry has invested a significant effort in developing methodologies for investigating maintenance errors. The literature on human error has its foundations in early studies of errors made by pilots (Fitts and Jones, 1947), work following the Three Mile Island incident, recent work in human reliability and the development of error taxonomies (Swain and Guttman, 1983; Norman, 1981; Rouse and Rouse, 1983; Rasmussen 1982; Reason 1990). This research has centered on analyzing maintenance accidents and incidents, a recent example being the Maintenance Error Decision Aid (MEDA) (Rankin et al., 2000). This tool, developed by Boeing, with British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the U.S. Federal Aviation Administration, helps analysts identify the contributing factors that lead to an aviation accident. Various airlines have also developed their own internal procedures to track maintenance errors. One such methodology employs the failure modes and effects analysis approach (Hobbs and Williamson, 2001) and classifies the potential errors by expanding each step of a task analysis into sub-steps and then listing all the failure modes for each substep. The US Navy Safety Center developed the Human Factors Analysis and Classification System – Maintenance Extension Taxonomy and the follow-up web–based maintenance error information management system to analyze naval aviation mishaps (Shappell and Wiegmann, 1997; Schmidt, et al., 1998; Shappell and Wiegmann, 2001). Later, this system was used to analyze commercial aviation accidents (Wiegmann and Shappell, 2001). Although valuable in terms of their insights into identifying the performance-shaping factors that lead to maintenance errors, these efforts tend to be reactive in nature; i.e., their focus is on analyzing maintenance accidents and errors following their occurrence, rather than developing preventive measures. Moreover, these efforts often tend to be ad hoc, varying across the industry, with little standardization. Analyzing the efficacy of maintenance and inspection procedures is of primary importance in order to proactively identify the potential factors contributing to improper maintenance. This can be achieved by closely monitoring and evaluating aircraft maintenance and inspection activities. As a part of this evaluation, surveillance of maintenance and inspection activities is conducted in a rigorous fashion by the quality assurance department of an airline. The surveillance and auditing activities constantly monitor and evaluate the flight procedures to determine their level of compliance. The objective of these activities is achieved through effective functioning of the quality assurance representatives and auditors who perform these activities. Their findings help in the evaluation and assessment of the internal and external organizations associated with the airline which influence the safety and airworthiness of aircraft. The surveillance and auditing activities are of foremost importance in ensuring adherence to the quality assurance requirements and also maintaining a consistent level of supervision over maintenance operations. Given this scenario, the goal of surveillance and auditing activities can be achieved through implementation of a system that documents the processes and outcomes of maintenance activities and makes this documentation more accessible. Thus, there is a need to develop a system that ensures superior performance of these activities. This system should perform the following functions:

1. Seek input from diversified sources
2. Proactively identify contributing factors
3. Promote a standardized format for data collection, data reduction and data analysis within and across the aircraft maintenance industry
4. Generate trend analysis for problem areas (causal factors within and across organizations)

In response to this need, this paper reports on a project to develop a proactive surveillance and auditing tool and devise strategies that enable identifying future problem areas. The identification of these problem areas will allow the industry to prioritize factors that apply across the industry to systematically reduce or eliminate potential errors. The work will be done in collaboration with FedEx in Memphis, Tennessee. The system will be a web-based application which will initially be developed with FedEx as the aviation partner and later will be made available as an application that can be used by other maintenance facilities. The objective of WebSAT is to proactively capture maintenance errors. The system will capture and record errors that occur during maintenance and inspection and supports analysis of this data. The specific objectives of this research are to

(1) Identify an exhaustive list of performance variables that potentially impact the aviation safety and transcend various aircraft maintenance organizations;

(2) Develop data collection/reduction and analysis protocols to analyze errors for the identified set of impact variables; and

(3) Using the results of the aforementioned activity, develop and implement a surveillance/monitoring tool which assures that a consistent level of oversight is maintained.

Background

The Quality Assurance (QA) department of FedEx will be the primary user of this tool. However, the needs of the Surveillance, Auditing and Airworthiness Directives groups will also be addressed.

Surveillance. Surveillance is the day-to-day oversight and evaluation of the work contracted to an airframe substantial maintenance vendor to determine the level of compliance with FedEx's Continuous Airworthiness Maintenance Program (CAMP) and General Maintenance Manual (GMM). The primary objective of surveillance is to provide FedEx, through the accomplishment of a variety of specific surveillance activities on a planned and random sampling basis, an accurate, real-time, and comprehensive evaluation of how well each substantial maintenance vendor is complying with FedEx and FAA approved CAMP, GMM, and regulatory requirements. A QA representative, stationed at the vendor location, schedules surveillance of an incoming aircraft. The specific task to be performed on an aircraft at a vendor location is available on a work card. The representative performs surveillance on different work cards according to the surveillance schedule. The results are documented and used to analyze the risk factors associated with that particular vendor and that particular aircraft.

Auditing. Audits are a more formal activity that addresses specific issues. A request sent to the QA technical audit manager from any department triggers an audit. The manager will assign an auditor and schedule the audit. The auditor will select the audit standards, perform pre-audit analysis and finally complete the audit. The auditor then reports the findings to the manager. This results in a 'Corrective Actions' document. These audits are recurrent. Oversight of functions relating to aircraft line maintenance, ramp operations and aircraft fueling, whether FedEx owned or contracted, is accomplished by a formal system of technical audits performed by qualified FedEx Senior Technical Auditors.

Airworthiness Directives Control. The Airworthiness Directives Control Group (ADCG) is responsible for the implementation of new, revised or corrected Airworthiness Directives (AD) appearing in the Federal Register. If the "applicability statement" of an AD refers to an aircraft model and series or engine model and series operated by FedEx, or if the AD addresses an appliance or component that could be installed on an aircraft operated by FedEx, the ADCG considers the AD to be initially applicable. A Work Instruction Card (WIC) generated by the ADCG is used by the appropriate mechanics to check for compliance with the AD. There are checklists to review the compliance of a WIC. These checklists can be used as a process measurement tool to review each WIC and identify any discrepancies. The findings obtained from these reviews can be used to identify risk factors. Follow up of these discrepancies results in corrective actions.

Methodology

A task analytic and user-centered software lifecycle development methodology will be applied to this research. A comprehensive view of the different surveillance and auditing processes, their functions and the different tasks involved in accomplishing these processes will be developed. Research will be conducted to identify the process measurement variables and performance metrics that potentially impact aviation safety. These performance metrics are termed *impact variables,* since they potentially impact the safety of the aircraft. It will be ensured that the variables identified are appropriate and are representative of those used by other maintenance entities. This will be done by working with other airline maintenance facilities (e.g., those of other airlines and third party repair stations). Subsequently, the list of impact variables and the limitations and protocols for the use of specific data sources with the surveillance and auditing tool will be finalized.

The product design and development phase will be guided by a user-centered design methodology that enables the development of tools that perform at a high level in the hands of the end user. The structured approach of contextual design will be used to gather and represent information acquired (Beyer and Holtzblatt, 1998). The following principles (Gould and Lewis, 1985) guide our application of structured design methodology:

1. Early and continual focus on users and their tasks. This requires direct contact with users, including discussion and observation of their tasks and work environment, and identification of their wants and needs.

2. Empirical testing with users. This involves users doing real work with mockups and prototypes of product concepts.

3. Iterative design. This involves refinement of the design, based on the results of user testing, to bring the product into conformance with explicitly stated performance specifications.

The process of product design and development progresses through several phases.

Planning Phase. This phase includes the assessment of technological developments and project objectives. The output of the planning phase is a project mission statement which specifies a vision for the product, the target market, project goals, key assumptions, constraints, and stakeholders. The mission statement for WebSAT is given in Figure 1. The product vision statement briefly presents the key customer and user benefits of the product, but avoids implying a specific concept. To ensure that the appropriate range of development issues is addressed, all WebSAT stakeholders, i.e., the groups of people who will be affected by WebSAT, are identified and listed in the mission statement. This stakeholder list begins with the end user and customer but also includes those people tasked with installing, managing, and maintaining WebSAT. The list of stakeholders helps to ensure that the needs of all who will be influenced by WebSAT are identified and considered in its development. This mission statement essentially summarizes the direction to be followed by the product development team (Ulrich and Eppinger, 2004).

Needs Analysis Phase. The needs analysis phase creates a high-quality information channel between the customer and intended users, and the developers of the product. It requires that the product developers interact directly with the customers and users, and that they observe and experience the environment and context in which the product will be used. This helps ensure that technical tradeoffs are made appropriately during the development process and increases the likelihood that innovative solutions to user needs will be discovered. The WebSAT team is currently conducting interviews to identify FedEx's needs with respect to documentation and access to surveillance and auditing activities.

Mission Statement: Web-based Surveillance and Auditing Tool Prototype	
Product Description	• A distributed application, incorporating a recommended categorization and data collection scheme for maintenance surveillance and auditing application • A data reduction module that allows analysts to conduct data analysis module that facilitates trend analysis
Key Business Goals	• Achieve standardized data collection, reduction and analysis of maintenance errors across geographically dispersed entities of the airline industry • Develop a proactive system that captures maintenance errors • Accomplish trend analysis in future versions of WebSAT
Primary Market	• Federal Aviation Administration (FAA)
Assumptions & Constraints	• Develop WebSAT such that it adheres to FAA standard research software design specifications (For e.g., SQL server, ASP.NET, PHP)

Stakeholders	• FAA • FedEx QA Department • QA representatives/auditors • Information Technology department • Other airlines

Figure 1: Mission Statement for WebSAT

Gathering of Stakeholder Data. This process seeks to identify what the stakeholders need to support their performance and utilization of maintenance audits. The methods used to collect this data include interviews, focus groups, observations of the use of the existing system, and the analysis of documentation describing current procedures and regulations for maintenance auditing. While the primary user group to be studied during this phase will be the quality assurance personnel who carry out the auditing task, those who use the data collected through the audits and those who must manage and maintain the auditing process will also be included.

Interpretation of the Raw Data in Terms of Customer Needs. The verbatim statements of the stakeholders and the information gleaned from observations of the existing audit process and documentation will be translated into a set of user need statements and a task description. The need statements express stakeholder needs in terms of what an improved human-machine system has to do, but not in terms of how it will be done. The needs will be organized into a hierarchical list of primary and secondary needs using affinity diagramming. The primary needs are the most general categories, while the secondary needs express specific needs in more detail. The task description will be used to develop a set of representative task scenarios and to perform a detailed task analysis. A task scenario describes activities, or tasks, in a form that allows exploration and discussion of contexts, needs, and requirements with users. It avoids making assumptions about the details of a particular interface design. The task analysis assists in the identification of the specific cognitive and manual processes critical in the performance of the auditing task, as well as existing human-machine system mismatches leading to inefficiency and error (Gramopadhye and Thaker, 1998; Hackos and Redish, 1998).

Establishment of the Relative Importance of the Needs. A sense of the relative importance of the various needs is essential for making trade-offs and allocating resources in the design of a product. For this purpose, stakeholders will be surveyed to rate the relative importance of the needs that have been identified.

Product Specifications Phase. A preliminary set of target specifications, spelling out in precise, measurable detail what the product has to do, will be determined from the list of stakeholder needs. User-centered design involves specifications that address not only the functionality of WebSAT--what WebSAT has to do--but also the constraints under which WebSAT must operate. These constraints include environmental and context-of-use specifications, user specifications based on the characteristics of the intended user group, and usability specifications. The latter typically include metrics and target levels of performance with respect to effectiveness, efficiency, safety, utility, learnability, and memorability.

Conceptual Design Phase. The conceptual design phase transforms the needs and specifications developed in the previous phases into conceptual models which result in the generation of deign concepts. The task description, analysis, and scenarios provide clarification of the problems that must be solved. External search, including the benchmarking of related existing products, and internal search, in consultation with the stakeholder groups, are used to generate promising design concepts. These concepts are then explored systematically, through the development of low-fidelity prototypes. These prototypes enable comparative evaluation through interviews and simulation tests with representative users, as well as expert reviews, such as heuristic evaluation and cognitive walkthroughs. The product concepts are then refined and combined to determine the most promising design, the one that is subsequently designed in detail. The target specifications are then refined, based on the concept selected.

Initial Design Phase. The refined product specifications and the selected product concept form the basis for the construction of the details that, together, fulfill the selected design concept. In carrying out this activity, the concepts, principles, and methodologies of human-computer interface design will be applied to satisfy stakeholder needs. An initial working prototype of the product will be coded and debugged. This prototype will include: an event recording component that incorporates a recommended categorization and data collection scheme for maintenance auditing/surveillance application; a data reduction component that allows analysts to conduct central tendency analysis; and a data analysis module that facilitates trend analysis.

Iterative Test and Refinement Phase. The initial prototype will be tested with representative users and other relevant stakeholders to determine how well the design satisfies stakeholder needs. Based on the results, a series of iterative cycles of prototype refinement and evaluation will be carried out to ensure the development of a product that meets stakeholders' requirements in terms of functionality, efficiency, utility, usability, and acceptability. The evaluation methodologies used will include expert reviews, such as heuristic evaluation and cognitive walkthroughs, and usability testing.

Implementation Phase. In this phase, the product will be delivered to FedEx for trial use. Documentation and training materials will be developed and supplied. The use of the tool will be demonstrated and documented through the collection of data in a real-world environment.

Discussion

WebSAT is intended to enhance the utility of surveillance, auditing and airworthiness directive activities associated with commercial aircraft maintenance. This tool will be helpful in identifying risk factors and thereby generating a safety index for maintenance operations. Standardization of data facilitates the identification of potential problems areas at multiple and geographically dispersed maintenance sites. The tool can incorporate checklists and other verification standards used in auditing to achieve standardization of data collection, data reduction and data analysis. The maintenance personnel and quality assurance representatives who provide input to the tool from diversified sources should be able to access trends in the data proactively. This gives ownership to the personnel of the data that is being collected. The tool should also support the activities of the airworthiness directives group of FedEx, helping them to assure compliance with ADs. Essentially, WebSAT should ensure that a consistent level of oversight is maintained in performing surveillance and auditing activity, thereby achieving an aircraft maintenance system that is more robust and safer.

Conclusions

As we proceed in accomplishing the goal of WebSAT, we envision a tool which can perform superior trend analysis of the risk factors that lead to maintenance errors within and across commercial air carriers. This research will directly support the FAA's mandate to reduce maintenance-related accidents and errors by conducting guidelines-based human factors research and identifying and implementing intervention strategies.

Acknowledgements

We would like to thank Jean Watson and William Krebs from FAA, and Rocky Ruggieri, Ken Hutcherson and the QA department team from FedEx for providing their continuous support in conducting this research.

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